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The Ven. Archdeacon Garbett, Chichester,
was balloted for and duly elected a Fellow of the Society.

On the Indications by Phenomena of Atmospheres to the Sun, Moon, and Planets. By Professor Challis.

As the Earth has an atmosphere, it is not unlikely that the other bodies of the solar system are similarly furnished, and the knowledge we have of our own atmosphere may reasonably be employed in inquiring whether the existence of other atmospheres of the same kind is indicated by phenomena. I propose, therefore, in this communication to discuss generally the possible effects, observable from a distant position, of an atmosphere constituted like the Earth's, with the view of ascertaining whether such effects have been actually observed.

The most notable effect of the Earth's atmosphere is the refraction of the rays of light which pass through it. In consequence of this refraction, the apparent magnitude of the Earth, as seen by a distant spectator, would be in some degree greater than the apparent magnitude of the globe deprived of its atmosphere, because the rays which pass from the periphery of the globe to the position of the spectator must have a curved course concave to the straight line joining that position and

the Earth's centre. It happens that we are able to calculate exactly the amount of the augmentation in the case of the Earth, independently of any law of variation of the density of the atmospheric strata. I am indebted to Professor Adams for pointing out to me that this inference may be very simply drawn from the construction given by Mr. Sang, in a "Note on the Method of Computing the Moon's Parallax," contained in vol. xv. p. 169, of the *Monthly Notices*. The ratio of EK to EL, which is the ratio of the refractive index for the lowest stratum of the atmosphere to that for the highest, becomes, for the case of a ray which just grazes the Earth's surface, the ratio of EK to EA. Supposing the spectator to be placed at the Moon, this ratio is that of the Moon's horizontal parallax augmented by refraction, to the horizontal parallax unaugmented. As the refractive index for the highest stratum may be taken to be unity, if μ be the refractive index for the lowest stratum, we thus find that the augmentation is equal to $(\mu - 1) \times$ the Moon's horizontal parallax. This quantity is almost exactly $1''$. A mountain five miles high, situated at the Earth's apparent border, would subtend at the Moon an angle of $4\frac{1}{3}''$, and its top would be somewhat less elevated by the refraction than the base, on account of being higher up in the atmosphere. Thus it appears that the atmospheric refraction would only produce the effect of a slight apparent depression of the mountain. These results show that any atmosphere the Moon can be supposed to have would neither augment her apparent diameter to a perceptible amount, nor alter the forms of the inequalities on the periphery.

There is, however, another effect of atmospheric refraction which might determine whether or not a lunar atmosphere exists. We know that, to a spectator on the Earth, the Sun or a star remains visible above the horizon, by the effect of refraction, when its actual direction falls below the horizon. The same thing would happen to a spectator at the Moon. By reason of the bending of the rays in their passage through the Earth's atmosphere, a star about to be occulted would be visible when its actual direction from the place of the spectator falls within the Earth's apparent periphery. In consequence of the rays by which it is seen being successively more and more bent by the refraction, the star will appear to retire before the Earth's limb, and will disappear suddenly when the rays just graze the Earth's surface. Analogous effects would be produced at a reappearance: the star will be first seen to emerge from the limb when its proper direction falls within the Earth's contour, and will then separate from the limb at an increasing rate till it escapes from the influence of the terrestrial refraction. It is evident that if the Earth's apparent diameter were calculated from the observed times of such disappearances and reappearances, without taking any account of the effect of refraction, the result would be much less than the true value.

These considerations show that if the Moon has an atmosphere constituted like the Earth's, her apparent diameter, as inferred from the calculation of occultations of stars and eclipses of the Sun, would be less than the diameter obtained by instrumental measurement, provided the atmosphere produced a sensible amount of refraction. A large number of occultations of stars and planets observed at the Cambridge Observatory, the results of which are exhibited in final equations involving corrections of the quantities assumed in the calculations, might be used for determining this point. It would, however, be necessary in each instance to correct the place of the Moon and that of the star or planet; and, after all, the determination of apparent diameter would be uncertain on account of the liability to error being much greater in observing occultations at bright limbs than in observing those at dark limbs. As far as I have gathered from the mean of a large number of equations, on the supposition that the only error to be corrected is that of the Moon's assumed semi-diameter, the result does not appear to confirm the hypothesis of an atmosphere. On the other hand, the Cambridge observations of the Solar Eclipse of March 15, 1858, reduced so as to correct the tabular differences of the R.A. and N.P.D. of the Sun and Moon, give a correction of the Moon's semi-diameter in the *Nautical Almanac* equal to $-2''\cdot96$; and Mr. Airy obtained from a discussion of the Cambridge observations of the Solar Eclipse of July 16, 1833, a like correction equal to $-4''\cdot21$. (See *Memoirs of the Royal Astronomical Society*, vol. viii. p. 133, and vol. xxvii. p. 60.)

In an eclipse of the Sun by the Earth, as seen from the Moon, the terrestrial refraction would cause solar rays to reach the Moon, which come from parts of the Sun's disk that are really behind the Earth. There will, consequently, be a condensation of light, so far as this cause operates, bordering the Earth's limb, but extending a very little distance from it, since the whole height of the terrestrial atmosphere, assuming it to be 60 miles, subtends only an angle of $52''$ at the Moon. This light will be much diminished in intensity by having to pass through the dense parts of the Earth's atmosphere, as is evident from the fact that the Sun's face, when near setting, loses so much brightness that it can be looked at with impunity with the naked eye. Also, the rays from this fringe, being divergent, will on that account fall with less intensity on the Moon. But the fringe will remain, and a narrow strip of the Sun's face be apparent long after the disk is geometrically behind the Earth; and the light will generally acquire a ruddy colour by passing, for the most part, through the vapours near the Earth's surface. The red appearance of the Moon's disk during a total lunar eclipse is, as is well known, accounted for in this manner. If we now inquire whether any analogous phenomena are presented in an eclipse of the

Sun by the Moon, we may at once pronounce, considering that if there be a lunar atmosphere, it must be of extreme rarity, that no effect would be at all likely to be discernible, except a slight condensation of solar light bordering the part of the Moon's periphery which crosses the Sun's disk. It is stated by Professor Stephen Alexander, in an account of observations of the total Solar Eclipse of July 18, 1860, published by the Superintendent of the United States Coast Survey, that himself and two other observers saw "a bright band bordering the edge of the Moon which was projected on the Sun's disk." (Appendix, No. 21, to Report for 1860.) It might be doubted from this description whether the band was on the Sun's disk or the Moon's. But, as one of the observers says that he saw "the Sun brighter along the border of the Moon," I conclude that the band was exterior to the Moon's edge. Professor Alexander further states that he first noticed the phenomenon in 1831, and had since, on various occasions, called the attention of others to it; also that "the bright band is unquestionably pictured in the copies of daguerreotypes of the eclipsed Sun." I have referred to these statements in the hope that in future eclipses of the Sun, partial or total, observers may have their attention directed to this appearance, which, as bearing on the question of a lunar atmosphere, is of no little interest.

In the case of an occultation of a star by the Earth, as seen from the Moon, if the strata of the atmosphere were transparent and undisturbed, and everywhere of the same density at the same height above the Earth's surface, the rays by which the star is last or first seen would coincide with rays from the apparent periphery of the Earth, and the star at disappearance or reappearance would, consequently, appear to be exactly on the periphery. But disturbances and variations such as we perceive actually to take place in our atmosphere would destroy this coincidence, and cause the disappearances and reappearances to occur at points separated, on one side or the other, from the Earth's limb. Circumstances of this very kind have been noticed in occultations of stars by the Moon, and would seem to admit of explanation by the hypothesis of a lunar atmosphere. But, although such phenomena, and that above mentioned of the bright band bordering the Moon in a solar eclipse, are reconcileable with the supposition of an atmosphere, they would hardly suffice to prove its existence. An ascertained excess of the Moon's diameter, as measured, above the diameter determined by occultations of stars and solar eclipses, would be a crucial fact, inasmuch as it does not appear that this fact could be accounted for on any other supposition than that of a lunar atmosphere.

I proceed now to consider another effect of atmospheric refraction; in noticing which, as far as I am aware, I have not been anticipated by any previous investigator. Hitherto it has been supposed that a ray from a star or other object may

pass *through* the atmosphere in a course which grazes, or is a tangent to, the interior globe. It is evident that in such a case the curvature of the path of the ray is *less* than the curvature of the surface of the globe. But it is conceivable that there may be such a relation between the gradation of density of the atmospheric strata, and the curvature of the globe, that this condition cannot be fulfilled. For instance, it is reasonable to suppose that this is the case in the Sun's atmosphere, when the vast magnitude of the globe is considered, and the usual equation $-k\,d\rho = G\rho\,dz$ is taken into account, which shows that the decrement $-d\rho$ of density corresponding to a given increment dz of height varies conjointly as ρ the density and G the Sun's gravity. It will, therefore, be worth while to inquire what optical effects will result under these circumstances.

A ray of light proceeding from a point on the surface of the globe, in a direction making an angle with the surface less than a certain limiting angle (α), will not pass out of the atmosphere, but will either reach a maximum distance and then return by a like path to the surface again, or will be reflected internally from the upper atmospheric surface, if the atmosphere be of finite density at its superior limit. Conversely, a ray entering the atmosphere from an external body could not impinge on the surface of the globe in a direction making with it an angle less than α. It seems necessary to suppose that an atmosphere has an upper boundary like that of an ocean, because, the density continually decreasing with the height, a point must at length be reached at which the upward repulsive force of an atmospheric stratum is just equal to the force of gravity, in which case there can be no downward repulsive force, and therefore no further extension of the atmosphere. Now the limiting angle α is the angle made with the surface of the globe by the course of a ray, which, after traversing the atmosphere and being refracted at the boundary, issues out in the direction of a tangent to the refracting surface. No ray which comes to the eye of a distant spectator can be inclined to the surface of the globe at a less angle than this.

From these considerations it follows (1) that rays proceeding from points of the Sun lying *beyond* the surface which contains all these limiting courses cannot reach the eye of a distant spectator; (2) that rays proceeding from points *within* that surface appear to come from points within the Sun's periphery; (3) that rays proceeding from any points *on* that surface eventually are tangential to the boundary of the atmosphere, and appear to come from the Sun's periphery. Consequently, if the boundary of the atmosphere be spherical, the periphery of the Sun will be an exact circle, notwithstanding any actual inequalities of the surface of the globe. Also, if we may suppose that any objects like clouds are suspended in the solar atmosphere, all the points lying on the limiting

courses will be brought by the refraction to the same level, that is, to the level of the upper boundary of the atmosphere. The augmentation of the Sun's apparent diameter as seen from a distant point will be just equal to the apparent height of the atmosphere.

The foregoing theory fully explains why the contour of the Sun is generally observed to be entirely free from inequalities. This fact is the more remarkable because the unevenness of the Sun's surface, as indicated by the mottled appearance spread over its whole extent, with the occasional occurrence of deep depressions (the spots), surrounded generally by lofty ridges (the faculæ), gives reason to expect that inequalities would be perceptible on the periphery. I am aware that Mr. Dawes has recorded the observation on Oct. 22, 1859, of a phenomenon, which he describes as "a bright streak, which formed the very edge, projecting irregularly beyond the circular contour of the edge." (*Monthly Notices*, vol. xx. p. 56.) This observation, which, as being made by so experienced an observer, must be accepted as trustworthy, by proving the possibility of seeing inequalities, provokes the enquiry, Why are they not more generally seen? The above theory accounts for their not being visible under ordinary circumstances, and at the same time it is possible that the solar atmosphere may be liable, under abnormal conditions, to disturbances and changes of level sufficient to account for the phenomenon Mr. Dawes witnessed. Besides this instance of inequality of contour I am acquainted with only that which was observed on Aug. 4, 1862, by Mr. Howlett, who states that "he plainly perceived a small notch in the Sun's margin, which struck him as not being caused so much by any deficiency in the circular limb of the Sun itself, but rather by reason of abnormally heaped up masses of the contiguous photosphere." (*Monthly Notices*, vol. xxiii. p. 113.) This phenomenon would thus seem to be similar to that seen by Mr. Dawes, and might be due to the same kind of disturbance. In both instances the details of the appearances presented by the spots and faculæ are of an unusual character.

With reference to the second instance, I beg to state that on July 26, at 2^h P.M., I saw with the Northumberland Telescope of the Cambridge Observatory the remarkable spot which is the subject of Mr. Howlett's communication. Mr. Todd, the Junior Assistant, who called my attention to it in the temporary absence of Professor Adams, took a sketch of it. The sketch is, consequently, intermediate to those of July 25 and 27, figured in pp. 110 and 111 of the *Monthly Notices*, above cited. The peculiarity of small nuclei situated on the edges of large patches of penumbra is exhibited, with great changes in the details, in this as in the other sketches. What chiefly struck me was a bridge stretching across the principal nucleus, remarkably bright, and not bounded by a penumbra.

I judged it to be brighter than the general surface of the Sun. Mr. Howlett, describing its appearance on July 25, calls it "a remarkable mass of brilliant photospheric matter," at which time it had not decidedly assumed the form of a bridge. This phenomenon and the peculiarity above mentioned, with the dislocated appearance of the adjacent patches of penumbra, seem to be indicative of an unusual amount of disturbance.

With respect to indications of the existence of atmospheres to the planets, little can be said relative to the effects of atmospheric refraction. From what was proved at the beginning of this communication, the apparent semidiameters will most probably not be sensibly increased if the refraction be of the first kind; and if of the second kind, the increase would be the angle which the whole height of the atmosphere subtends at the Earth, and would vary with distance according to the same law as the apparent semidiameter. Supposing the refraction of *Jupiter's* atmosphere to be of the first kind, a satellite would probably be eclipsed as soon as the atmosphere interferes with its visual direction, because the deviation and divergence which the rays undergo by incidence on the atmosphere, might at once render them invisible at the great distance of the Earth. If otherwise, the satellite would diminish in brightness before disappearing, and such diminution might be taken as evidence of the existence of an atmosphere. If the refraction were of the second kind, the satellite would disappear without diminution of brightness, just as if it had been eclipsed by an opaque body. The most direct physical evidence of a planet's atmosphere would be the constant recurrence of variable appearances on the disk known not to be due to rotation, it being hardly conceivable that such appearances can have any other origin than the suspension and motion of cloud-like substances in an atmosphere. Such phenomena are observable on the disks of *Jupiter* and *Saturn*, and, as would seem from recent observations, on that of *Mars*.

It remains to notice one other phenomenon indicative of an atmosphere: a distant spherical body, whether self-luminous or shining by reflected light, would, according to the law that the intensity of the radiation varies as the sine of the angle which the direction of emanation makes with the surface, appear equally bright at all points of the disk. But an atmosphere to the body, of considerable magnitude and constituted like the Earth's, would intercept more of the rays coming from the parts near the periphery than of those coming from near the centre of the disk, because the former would pass through a greater thickness of atmosphere. There would, in consequence, be a gradual diminution of brightness from the centre to the circumference. This phenomenon is, in fact, plainly discernible in a photographic picture of the Sun, or in an image received on a screen, and is so simply explained by the above considerations, that it almost justifies of itself the inference that

the Sun has an atmosphere. The effect would be produced whether the atmospheric refraction be of the first of the two kinds before mentioned, or the second, but would be less conspicuous in the latter case than in the other. With respect to *Jupiter*, also, I have frequently remarked, that the features of the disk appeared more distinct near the centre than towards the periphery; and on the occasion of the occultation of this planet on January 2, 1857, I made the note that when it emerged from the Moon's bright limb, it appeared "brighter at the central parts than towards the border, and had in consequence something of a pellucid appearance." (See *Monthly Notices*, vol. xvii. p. 138). These phenomena are readily explained by the supposition of an atmosphere.

Cambridge, April 13, 1863.

On an Eclipse of the Sun recorded in the Chinese Annals as having occurred at a very early Period of their History. By Mr. Williams, Assistant-Secretary.

A few weeks since Mr. Hind requested me to look into the annals of China, with a view of ascertaining the particulars of a very early Solar Eclipse, said to be recorded in their most ancient historical work, the *Shoo King*, a copy of which is in my possession. I accordingly undertook the task, and the information thus obtained appearing to be of considerable interest, I am induced to lay it before the Society, it being the earliest record known of a Solar Eclipse. I therefore will very briefly give the result of this investigation, explaining, at the same time, the process by which it has been obtained. It is to be remembered that it is the Chinese account only I now lay before you, leaving its corroboration or disproval to those more competent than myself to enter into that part of the subject.

In the 書經 *Shoo King*—the most ancient historical work of the Chinese—in the second section of that work, under the 夏 Hea Dynasty, it is related that, in the reign of 仲康, Chung Kang, the fourth Emperor of that Dynasty, an Eclipse of the Sun took place. The passage recording this Eclipse occurs incidentally in an account of the delinquency of 羲 He and 和 Ho, two important officers, who appear to have had the superintendence of the Imperial Astronomical Board, as it may be called, and who, giving themselves up to wine, neglected their duties, and consequently, failing in the prediction of the Eclipse in question, rendered themselves